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October 10, 2013
Project No. 8128.01.20

Mr. Dana Bayuk
Oregon Department of Environmental Quality
2020 SW 4th Avenue
Portland, OR 97201-4987

Re: Fill WBZ Investigation Work Plan and DEQ Comments—Siltronic Corporation Property

Dear Mr. Bayuk:

On behalf of Siltronic Corporation (Siltronic), Maul Foster & Alongi, Inc. (MFA) is providing this letter in response to comments made by the Department of Environmental Quality (DEQ), the U.S. Environmental Protection Agency (USEPA), and the U.S. Army Corps of Engineers (USACE) provided in a letter dated August 23, 2013 (DEQ, 2011). In that letter, DEQ and EPA reviewed the *Fill WBZ Trench Investigation Work Plan – Shoreline Segments 1 and 2, NWN Natural Property and the Northern Portion of the Siltronic Corporation Property* (the work plan), prepared by Anchor QEA (AQ) on behalf of NW Natural (NWN), and submitted to DEQ on June 28, 2013.

The work plan provides NWN's approach to collecting groundwater and geotechnical information to support the planning and design of an interceptor trench (IT) in Fill Water-Bearing Zone (WBZ) on the Gasco Site and northern portion of the adjoining property owned by Siltronic. This letter builds on comments provided by Siltronic to NWN on the draft work plan[1], and responds to the Agency comments received in the DEQ letter. Per DEQ comments, this response includes recommendations for additional geotechnical data collection on the Siltronic property. Additional data needs required to support trench design and implementation are also identified.

Siltronic's position regarding the IT as a source control measure on the Siltronic property is unchanged by the Agency comments. Siltronic first expressed its concerns in a letter to DEQ dated September 30, 2011, and the issues were reiterated and discussed in a meeting with DEQ on August 23, 2013, and summarized in a follow-up email on August 27, 2013. Based on available information, Siltronic believes that the IT is not practicable or implementable on the Siltronic property before riverbank restoration. New information, which is discussed in this letter, regarding the safety and reliability of the construction method (biopolymer slurry

[1] Due to a limited review cycle, MFA was able to provide only general comments on the draft work plan in a June 26, 2013 email to NWN. In that email, MFA noted that the draft wok plan did not include adequate information to conduct the necessary geotechnical evaluation of construction feasibility for either of the proposed trench alignments.

stabilization) has also raised fundamental questions about the basis of the design included in the *Revised Final Design Report* (the Design Report; AQ, January 2012). Additional geotechnical information is anticipated to confirm this position. The following responses to Agency comments are intended to provide further understanding regarding this matter.

RESPONSE TO DEQ COMMENTS

Page 4 – Comment regarding Section 1.2 of the work plan

DEQ requests that NW Natural add evaluating construction of the interceptor trench in sections to the list of objectives.

Siltronic agrees that feasibility of installing the trench in sections should be evaluated by NWN. The ability to connect to an existing pipe in a deep slurry trench is difficult due to lack of physical access to and absence of visibility at the trench bottom. Standard slurry trench construction methods utilize above ground construction of pipe joints and structures then lowering or "sinking" the pipes and structures through the slurry to the trench bottom before backfilling; this approach is not feasible for structures and pipes already in-place and would require a standard trench layback to make such connections. NWN and/or DEQ should provide demonstrated examples of how the segmented slurry IT approach has been successfully completed with similar site conditions (i.e. adjacent to a river bank, fill profile and debris, etc.). If examples are not available NWN should revisit the basis for the design given DEQ's determination that the IT should be constructed in individual sections and in advance of the riverbank restoration proposed for the Gasco Sediment Site (GSS) project.

In addition to evaluation of constructing the IT in sections, alternate IT construction methods should be considered, and alternate technologies for Fill WBZ source control should be identified and evaluated in detail.

Page 5 – Comment regarding Section 4.2 of the work plan

DEQ considers the lack of geotechnical information other than CPT logs to be a data gap that should be addressed during the trench investigation. DEQ requests that drilling and sampling be conducted at a sufficient number of locations to support evaluations of the geotechnical properties of the material and the trench design.

Siltronic agrees that there is a lack of geotechnical data for the development of an interceptor trench; recommendations for geotechnical data along the proposed alignments are provided below (see "Geotechnical Scope of Work"). The lack of geotechnical information along the alignment on the Siltronic property is of particular concern as the soil properties are essential to evaluating the feasibility of the IT in general as well as the construction methods to be used to install the IT. It should be noted that the some of the current geotechnical characteristics of the riverbank are expected to change during riverbank restoration work due to the planned or likely removal of the toe of the slope, bank armor, and riverbank soil as part of the GSS remediation. These changes will consequently render unreliable any conclusions to be drawn from prior geotechnical data and analysis of the riverbank soils conducted for the purposes of supporting constructability decisions about the IT. That is, the in-river sediment removal and riverbank restoration project could fundamentally change the basis of the design as described in the Design Report, and the approach selected by DEQ based on that report.

Moreover, it is expected that buried debris will be encountered during installation of the trench. Buried debris is known to exist in the fill profile along the prospective trench alignments based upon previous site investigations. Previous experience with waterfront projects in the region, specifically along the Willamette River[2], indicates that significant amounts of buried debris commonly used to construct waterfront fill sites could adversely impact the constructability of a trench using the proposed biopolymer slurry method, especially in locations closer to the top of bank. The presence of debris creates heterogeneities in the soil matrix, which become failure points for trench walls during excavation. Failure of a trench wall during excavation will result in significant soil movement and settling, which will in turn damage adjacent surface and subsurface structures. Additional investigation, as described below in "Geotechnical Scope of Work", is required in order to locate potential debris that may be encountered during trench construction in order to minimize the risk inherent with the biopolymer slurry method.

Page 5 – Comment regarding Section 4.3 of the work plan

"…NW Natural will submit an evaluation of the Fill WBZ trench construction alternatives requested in DEQ's December 7, 2011 letter, including an evaluation of whether it would be beneficial to accelerate construction of the trench in the segments north and south of the FAMM leasehold on the Site. This alternatives evaluation will recommend a schedule for construction of all or portions of the trench; this schedule may propose that construction commence more or fewer than 6 months following HC&C startup, depending upon all relevant information at the time of the evaluation."

DEQ requests that NW Natural prepare and submit the Fill WBZ trench evaluation indicated above focusing on the length, alignment, construction sequence and schedule…

Siltronic agrees that a fully formulated work plan outlining construction methods, sequence, schedule, and all other pertinent information on the implementation and feasibility of the Fill WBZ trench be submitted once the data gaps have been filled. Information regarding the types of equipment used to complete the trench construction are necessary to evaluate

[2] Debris including refractory brick and demolition material has been identified in boring logs from the Gasco and Siltronic Remedial Investigations. Examples of other relevant projects include the Zidell Bank and Sediment remediation project (ZRZ Realty), access shaft construction for the East-Side Big Pipe project (City of Portland Bureau of Environmental Services).

surface (i.e. tracking) and subsurface (i.e. vibration, settling) impacts at the Siltronic site. Siltronic will rely on this information to assess the feasibility relative to site conditions, access, staging, and site layout. Work sequencing, including materials handling and logistics, should also be described in the work plan to anticipate any potential impacts to the site operations and environmental conditions with respect to ingress/egress of trucks, as well as the mobilization of heavy equipment.

GEOTECHNICAL SCOPE OF WORK

At Siltronic's request, CH2M HILL reviewed the *Fill WBZ Trench Investigation Work Plan Gasco/Siltronic* prepared for NWN in June 2013. In addition to the work plan, CH2M HILL reviewed the Agency comments dated August 23, 2013, and relevant background data for the proposed project. Relevant background data include soil borings and cone penetration test (CPT) soundings conducted north of Siltronic Fab 1; preliminary plans and specifications for the interceptor trench design (Glynn Geotechnical Engineering, April 2011); utility maps and building foundation plans (Siltronic, dates vary); historical aerial photographs showing development of the Siltronic site; and the *Northwest Natural-Gasco Site Interceptor Trench Design Report* (Glynn Geotechnical Engineering, April 2011).

CH2M Hill prepared a Technical Memorandum (Attachment 1), which summarizes the existing data, identified geotechnical issues related to short-, intermediate- and long-term stability of the IT, riverbank, and structures. These issues raise concerns regarding the basis of design for the IT, and are consistent with Siltronic's concerns that have been raised repeatedly since DEQ determined that IT construction should occur prior to riverbank restoration. CH2M HILL identified the following concerns for short-, intermediate-, and long-term stability of the proposed IT:

- Short-term stability – Settlement adjacent to the trench is possible at a horizontal distance equal to the trench depth, up to as much as two-times the trench depth. Settlement of soil adjacent to the trench could result in movement of the bank slope and/or foundation soils beneath the structure on the Siltronic site. Additionally, trenching through buried debris or rubble would likely cause trench failure by side-wall collapse or rapid loss of slurry fluid.

- Intermediate-term stability – Concerns for intermediate term stability include stability and volume control of the trench, settlement of the gravel backfill, migration of fines causing settlement, and improper backfill or installation of PVC sheet pile along the riverward face of the trench causing settlement. These concerns are increased by operation of the trench which will depress the water table and potentially cause settlement of fill layers or fine-grained native material.

- Long-term stability – The interface between the vinyl sheet pile, the existing fill, and/or the gravel backfill material will likely be weaker than the current condition. The plane of weakness will impact the static slope stability of the existing bank above the river, which could be further compromised if excavation of the bank or sediment were to occur as part of the in-water remediation at the GSS.

Regarding the existing geotechnical data, while there were several CPT tests performed on the Siltronic property, the majority of these were pre-drilled from 5 to 40 feet through the fill zone. Hence, additional CPT data in the fill zone is recommended.

The tech memo included recommendations for geotechnical, buried debris, and IT component data collection to properly evaluate constructability, as well as short- and long-term stability of the trench and river bank. These recommendations include:

- Geotechnical Data - A minimum of three geotechnical borings should be performed on the preferred alignment, with SPT samples taken at 2.5-foot intervals in the upper 40 feet. Where fine-grained soil is encountered, Shelby tube or Osterberg samples should be taken. Laboratory tests should be performed on fill material including moisture content, Atterberg limits, grain size, and percent passing the No. 200 sieve (P200). If fine-grained native soil is encountered, it should be sampled with Shelby tubes for laboratory strength and compressibility testing including consolidated-undrained triaxial testing (CUTX) with pore pressure measurements, and laboratory consolidation testing if groundwater drawdown is an issue. It is unlikely that the fill itself is uniform enough to sample and perform strength testing. The strength and consistency of the fill should be estimated through the SPT tests and the soil classification. The geotechnical borings should be a minimum of 100 feet deep in order to adequately evaluate the seismic stability of the riverbank and IT as a structure.

- Buried Debris Data - PVC casing should be grouted into the upper 50 feet of the boreholes to perform cross-hole tomography between the boreholes to identify buried debris or other obstructions. If significant obstructions are discovered between the boreholes, the preferred alignment should be shifted south, out of the obstructions. Additional, shallower (to bottom of fill layer) borings with casings may be required to perform additional tomography and delineate a clear alignment.

- IT Component Testing - Additional laboratory testing should be performed to delineate the interface friction between the vinyl sheet pile and the native fill material, as well as the granular drain material and the vinyl sheet pile. The strength and pore pressure response of the fine-grained layers should be adequate to also define those layers within the river area provided they can be correlated through existing CPT soundings that were taken in the river.

The locations of the borings should be placed along the preferred alignment, or alternative alignments. However, as discussed below, mapping of the original and DEQ proposed alignments has raised significant practicability questions regarding the existing alignments. If an alternative IT alignment or construction method cannot be developed given the site constraints, alternative technologies should be evaluated.

GENERAL COMMENTS AND CONCERNS

Siltronic understands that the original concept for the IT was based on the recommendation that it be constructed **after** the in-river and riverbank remedies. However, it is DEQ's current position that the interceptor trench be constructed prior to these GSS remedies. Therefore, the design basis for this component of the HC/C system must be reexamined.

The preliminary design proposal provided by Anchor QEA shows two proposed alignments for the WBZ trench on the Siltronic property. The original alignment (Alternative 1) runs immediately along the top of bank, and the secondary alignment (Alternative 2), as proposed by DEQ, runs adjacent to the Fab 1 building extension (Figure 1)[3]. As noted above, geotechnical data should be collected within these alignments. However, evaluation of this figure has raised the following significant issues indicating that the IT may not be practicable along either of these alignments.

Alignment Location – Both alignments pose significant safety or logistical concerns regarding slope stability, building stability, and the integrity of the alluvial hydraulic control/containment (HC/C) system components. Figure 2 shows the proposed alignments, and illustrates several safety or logistical issues.

- Slope stability concerns are associated with placing the trench at the top of bank location (Alternative 1). Proposed in-water remedial action activities currently include dredging and excavation at the base of the bank slope, the lateral extent of which is yet to be determined and could be adjacent to the IT. Excavation of the slope and sediments at the toe of the slope is anticipated to decrease overall bank stability, especially with the shear plane created by the IT, as noted in the CH2M Hill memorandum. Lack of data regarding the composition and physical properties of the fill material through which the trench would be constructed area also problematic, in that encountering rubble, large debris, or other highly permeable materials during trench construction could cause rapid loss of slurry fluid and result in trench failure.

[3] Alignments based on GIS shapefiles provided by AQ.

Trench failure would cause additional soil movement which could increase settlement and decrease bank stability.

- Both alignments require clearing access on either side to allow for equipment operation and maintaining minimum safety zones for workers. These are shown as the yellow and orange footprints on Figure 2, and they intersect multiple permanent surface features (such as the HC/C system components).
- The alternative alignment (Alternative 2) proposed adjacent to the Fab 1 building extension does not consider that the IT should be located a minimum distance away from the existing building to avoid impacts to the structure from soil settlement. The primary impact of the trench on surrounding soil (settlement) for a well-constructed and fluid filled trench is anticipated to occur within a horizontal distance equal to the trench depth (approximately 35 feet), or 1:1 horizontal to vertical (H:V). Impacts may be experienced as much as two-times the trench depth, or 2:1 (H:V) for less desirable trench conditions (i.e., unconsolidated fill material)[4] consistent with site conditions. Utilizing a 2:1 horizontal setback, the IT alignment would be located at least 70 feet from the Fab 1 extension building foundation. Additionally, numerous other structures including the access road, subsurface utilities, and the HC/C system fall within the 2:1 H:V footprint and would need to be protected and avoided, or relocated. Until DEQ or NWN can determine otherwise, Siltronic will require at least a 2:1 setback from existing structures for the purpose of safety and preserving structural integrity.
- These alignments will require removal and replacement of critical infrastructure, including utilities and the HC/C system required for source control. These utilities include, but are not limited to, stormwater collection and conveyance structures, high voltage electrical conduit encased in a concrete vault, a fire protection water system, and alluvial groundwater extraction wells (the HC/C system) and transmission lines.

Access and Work Sequencing – As mentioned above, additional information regarding the types of equipment used to complete the trench construction must be provided to evaluate feasibility with site conditions. For the analysis on Figure 2, MFA has assumed standard excavating equipment and identified operational areas based on equipment specifications. If alternative equipment or methods are proposed to allow for a different alignment alternative, this information should be included and the Design Report should be updated.

Trench Construction Method – The work plan assumes data collection to support the design and installation using polymer slurry to maintain trench wall stability. This technology is not proven at the Siltronic site, and is apparently prone to unpredictable failure. The attached

[4] Trench impact distances based on recommendations provided in the CH2M HILL technical memorandum (Attachment 1).

paper (Attachment 2) documents the failure of polymer slurry in an application remarkably similar to the proposed IT with the following excerpt:

> During the trench excavation on the western portion of the site (in a 30 m section of the trench), ARCADIS BBLES and its subcontractor, Geo-Solutions, observed that the biopolymer slurry level dropped significantly (approximately 2.5 to 3 m bgs) within a short time period (approximately 10 to 20 minutes)…After the significant drop in the biopolymer slurry level, cracks began to develop in the Court Street asphalt pavement approximately 7.5 m downgradient from the excavated trench. As a result of this condition, the trench was immediately backfilled with pea gravel to prevent further damage. This effort required working around the clock to backfill the trench as quickly as feasible to prevent additional damage, as well as closing a portion of Court Street to prevent vehicular traffic from travelling over the cracked area. Once the trench was backfilled with pea gravel, the area was stabilized and no further movement of the asphalt pavement was observed.
>
> Additional efforts were made to determine the cause of the biopolymer slurry loss; however, these efforts were unsuccessful and the cause of this biopolymer slurry loss could not be determined. These efforts included re-excavating areas along the trench to locate potential voids or pipelines, as well as observing areas along the north bank of the Susquehanna River adjacent to the site. Based on these efforts, there were no observations of voids or pipelines within the trench, and there were no observations that the biopolymer slurry drained to the river.
>
> As a result of quickly backfilling the trench with pea gravel, various components of the DNAPL and LNAPL collection systems were not installed.

This outcome demonstrates that polymer slurry stabilization is prone to catastrophic and unpredictable failure, even when pre-design information is collected. DEQ or NWN should provide additional information demonstrating successful trench completion with biopolymer slurry in materials similar to the Siltronic site before this approach can be further evaluated for slope stability and safety.

As a general comment, and based upon the above and the analysis in the attached Technical Memo, neither alignment Alternative appears feasible for an IT. Locating the IT closer to the top of bank will conflict with or otherwise limit subsequent in-river restoration options, whereas locating the IT closer to Fab 1 will conflict with surface and subsurface structures and will impact source control infrastructure. An alternative technology is warranted if installation prior to riverbank restoration is required.

SUMMARY

This response identifies geotechnical data gaps that require resolution to evaluate the current design. However, evaluation of the IT alignments in the context of additional information has raised practical issues that question the basis of the design, and the installation sequence selected by DEQ. These issues require resolution by NWN, Siltronic, DEQ, and USEPA before additional work should be performed.

Siltronic continues to disagree that installation of the interceptor trench in advance of riverbank restoration is feasible at either of these alignments. Regardless of in-water work sequencing, the site constraints described in this document limit or otherwise diminish the viable locations for the trench as currently designed. By copying USEPA on these comments, Siltronic hopes to initiate discussions between USEPA and DEQ to resolve the continuing disconnect resulting from DEQ's decision regarding IT installation and sequencing relative to the EPA-directed in-water and riverbank work, and the as-yet undetermined lateral and vertical extent of sediment and upland bank excavation and restoration efforts contemplated for the GSS.

Siltronic further notes that the fundamental issue of sequencing and integrating upland and in-river work has not been fully evaluated in an open discussion between DEQ, USEPA, NWN, and Siltronic. This is demonstrated by recent Agency communications regarding upland source control:

> *(DEQ, in correspondence to NWN, 9/22/2011)* [Source control measures] SCMs should not limit NW Natural's ability to implement effective remedial alternatives to address the riverbank. Implementation of groundwater SCMs should satisfy two conditions: 1) the interceptor trench and HC&C system should preserve maximum flexibility in accommodating the range of options for remediating bank soil and river sediment, and 2) future riverbank work should not interfere with construction of groundwater SCMs or compromise groundwater SCMs during riverbank sediment remedy construction.
>
> *(From USEPA to NWN and Siltronic, 8/30/2013)* Hydraulic control and containment (HC&C) structures will not likely be considered as obstructions without substantial justification because the potential for in-water work to involve areas occupied by uplands source control measures (SCMs) has been recognized as a reasonable scenario for years. Consequently, the locations of SCMs, including the HC&C components of the groundwater SCM, have considered this scenario in the planning and design process.

From this correspondence, it appears that the two agencies' opinions are in conflict regarding the implementation sequencing and continued operation of upland and in-river remedies. We therefore request that the DEQ and USEPA convene a meeting with Siltronic and NWN to resolve this conflict before any additional work on the IT continues.

Sincerely,

Maul Foster & Alongi, Inc.

Jacob Faust, PE
Project Engineer

James G.D. Peale, RG
Principal Hydrogeologist

Attachments: Figures

1 – Review of Investigation Work Plan for Fill Water-Bearing Zone Trench for Siltronic, Portland, Oregon; CH2M Hill, September 4, 2013

2 - Passive NAPL Barrier Design and Construction; ARCADIS (2007)

cc: Myron Burr, Siltronic Corporation
Koreen Lail, Siltronic Corporation
Alan Gladstone, Davis Rothwell Earle & Xochihua
Brian Church, Davis Rothwell Earle & Xochihua
William Earle, Davis Rothwell Earle & Xochihua
Chris Reive, Jordan Shrader Ramis
Keith Johnson, DEQ
Tom Gainer, DEQ
Henning Larsen, DEQ
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Kristine Koch, EPA
Sean Sheldrake, EPA
Rene Fuentes, EPA Seattle
Chip Humphrey, EPA Portland
Lance Peterson, CDM
Bob Wyatt, NW Natural
Patty Dost, Pearl Legal Group
John Edwards, Anchor QEA LLC
Ben Hung, Anchor QEA LLC
John Renda, Anchor QEA LLC
Carl Stivers, Anchor QEA LLC
Rob Ede, Hahn and Associates, Inc.

FIGURES

Source: Aerial photograph obtained from Esri ArcGIS Online.

Legend

- Proposed Trench
- Gasco Station
- MFA Siltronic Monitoring Well
- TarGOST Boring (Approximate)
- Siltronic Tax Lot (2013)

Figure
Proposed Trench Alternatives 1 & 2

Siltronic Corporation
Portland, Oregon

0 20 40
Feet

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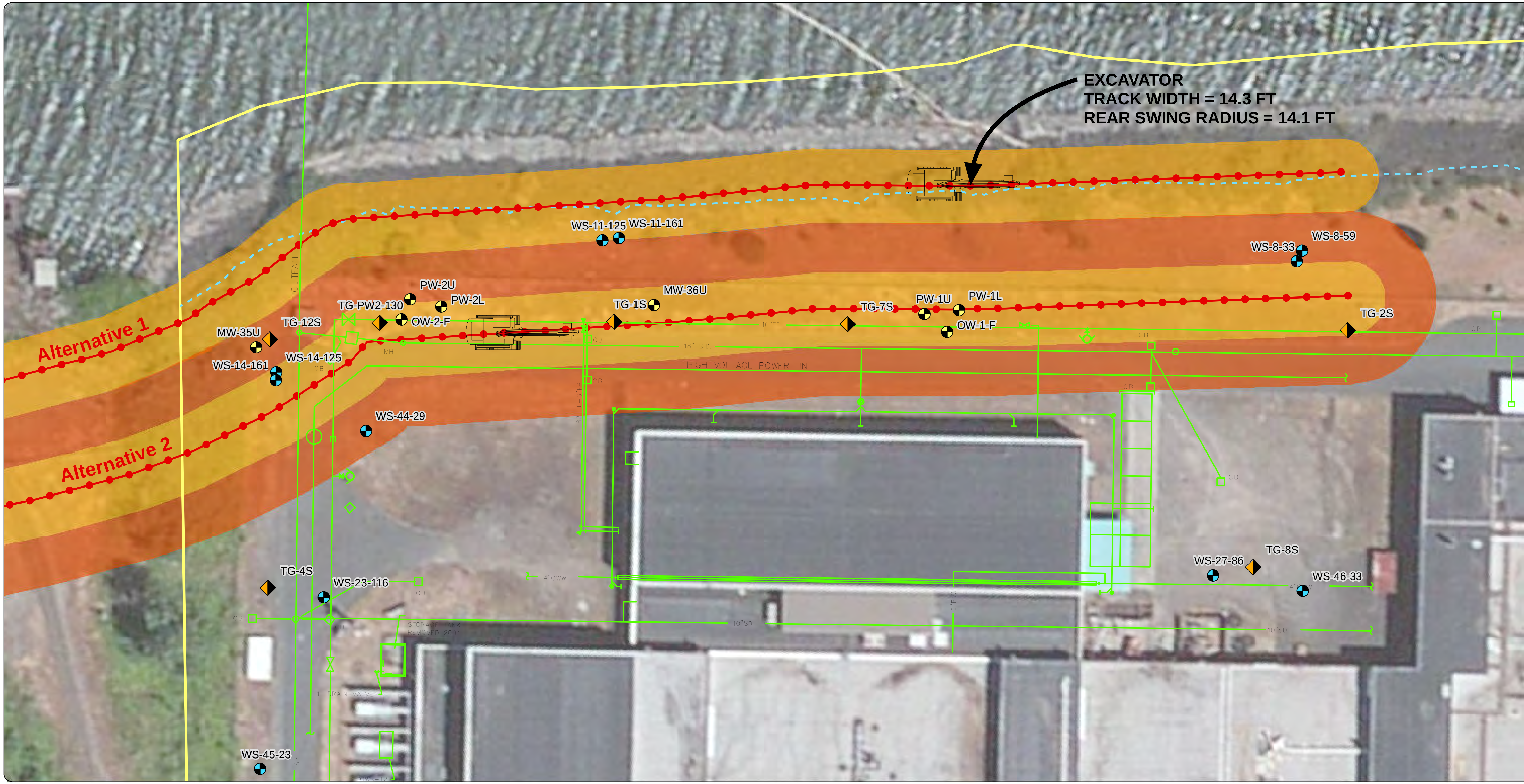
Path: X:\8128.01 Siltronic Corp\12\Projects\05\Fill Zone Well Installation\Fig1_Proposed Trench Alignment.mxd
Print Date: 10/7/2013
Approved By: J. Peale
Produced By: jschane
Project: 8128.01



Source: Aerial photograph obtained from Esri ArcGIS Online. Utility overlay map provided by Siltronic.

Legend

- Gasco Station
- MFA Siltronic Monitoring Well
- TarGOST Boring (Approximate)
- Top of Bank (Approximate)
- Utility Line (Siltronic)
- Siltronic Tax Lot (2013)
- Proposed Trench
- 15 Foot Buffer
- 35 Foot Buffer

Notes:
1. 15 foot buffer based on the tail swing radius of an Hitachi ZX800 Hydraulic Excavator.
2. 35 foot buffer is the distance away from structures or other surface impacts based on a 1H:1V equivalent of the excavation depth.

0 20 40
Feet

Figure 2
Proposed Trench Alternatives 1 & 2

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Portland, Oregon

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Produced By: jschane
Project: 8128.01

ATTACHMENT 1

REVIEW OF INVESTIGATION WORK PLAN FOR FILL WATER-BEARING ZONE TRENCH FOR SILTRONIC, PORTLAND, OREGON

CH2M HILL

Review of Investigation Work Plan for Fill Water-Bearing Zone Trench for Siltronic, Portland, Oregon

PREPARED FOR: Myron Burr/Siltronic

COPY TO: James Peale/MFA
Alan Gladstone/ Davis
Rothwell Earle & Xochihua P.C

PREPARED BY: David Dailer/CH2M HILL

DATE: October 4, 2013

PROJECT NUMBER: 480755.02.LB.00.00

Introduction

Northwest Natural and their Contractors are proposing to design and construct an interceptor trench extending from nearly the west end of the Northwest Natural site, and up to 400 feet into the west side of Siltronic's site. At Siltronic's request, CH2M HILL has reviewed the Anchor QEA document for the *Fill WBZ Trench Investigation Work Plan* Gasco/Siltronic prepared for Northwest Natural Gas in June 2013. In addition to review of the work plan, CH2M HILL has reviewed the Oregon Department of Environmental Quality response dated August 23, 2013, and relevant background data for the proposed project. Relevant background data include soil borings and cone penetration test (CPT) soundings conducted north of Siltronic Fab-1; preliminary plans and specifications for the interceptor trench design (Glynn Geotechnical Engineering, April 2011); utility maps and building foundation plans (Siltronic, dates vary); historical aerial photographs showing development of the Siltronic site; and the Northwest Natural-Gasco *Site Interceptor Trench Design Report* (Glynn Geotechnical Engineering, April 2011).

Based on the documents that were reviewed, the proposed interceptor trench on the Siltronic site is approximately 3.5 feet wide by 35 feet deep, extending from the ground surface to the bottom of the surficial site fill. The trench drain would be constructed as a slurry trench, utilizing a biopolymer compound to support the trench during construction. The biopolymer would subsequently degrade so as not to diminish the permeability of the adjacent ground. The slurry trench would be backfilled with an open-graded gravel, with a collector pipe in the bottom of the trench sloped toward the Northwest Natural site. One side of the trench (the south side) would be lined with a geotextile to prevent migration of native material into the gravel layer, and the north side of the trench would be lined with a Z-shaped vinyl sheet pile section to mitigate the infiltration of river water.

Scope of Work

The scope of the work is broken into two tasks, as detailed below.

Task 1—Review Existing Data

- Review existing data including soil borings, well logs, CPT data, historical data, and utility and building data from the Siltronic site; emphasis on explorations and data near the proposed upland source control measure.
  - CH2M HILL has assumed that Maul Foster Alongi has complete records of the data and can provide the necessary information to CH2M HILL; data should include boring logs prepared from field notes, geotechnical laboratory test results, and CPT logs comprising numerical output in either Excel or text format.

- Summarize existing data, evaluate quality and completeness for application to bank and trench stability issues, and assess potential impact on Siltronic's facilities.

Task 2—Recommend Data Collection Strategy to Support Geotechnical Evaluation of Trench Design

- Evaluate the number, type, depth, and coverage of geotechnical explorations needed for the project.
- Evaluate extent and suitability of potential data necessary for performing slope stability analysis and slope/surface deformation analysis; includes locations, depths, and type of explorations to be performed, as well as types of samples to collect and laboratory tests to perform.
  - Data to include stratigraphy, soil gradation, soil strength, soil permeability, soil compressibility, index parameters such as moisture content, Atterberg Limits, pH, and other properties that may impact the design.
- Prepare a short memorandum summarizing data gaps and recommendations regarding data that should be collected for the water-bearing zone (WBZ) interceptor trench design.

Summary of Existing Data

A significant amount of environmental data has been collected through the corridor north of Fab-1. The explorations consist of soil borings, soil probes, and CPT probes. The soil borings were performed generally using rotosonic drilling techniques. Rotosonic drilling consists of rotating and vibrating a casing into the ground in 5- or 10- foot increments and retrieving nearly continuous cores of material using a wireline retrieval system. The cores are typically 4- or 6-inch diameter. The main advantages of rotosonic drilling are (1) the recovery of near-continuous cores that provide good stratigraphic and soil index information, and (2) the capture of good samples of gravel too large for most samplers. The disadvantage is that no standard penetration tests (SPTs) are performed and no "undisturbed" soil samples are recovered. SPTs are helpful in determining the relative density of granular soils, and the relative stiffness of cohesive soils. Undisturbed samples are typically used in laboratory testing to determine the engineering properties of soils, such as shear strength, compressibility, and permeability.

Additional soil probe samples were collected using a geoprobe sampler. Geoprobe samples are also collected continuously. A sampler is driven into the formation and samples are collected in 3.28- or 4-foot (1.0- to 1.2-meter) intervals and retrieved in an acetate sleeve. The geoprobe samples are smaller (approximately 2-inch diameter). Geoprobes also provide good information on soil stratigraphy, but are not as good at collecting gravel samples because of the smaller sampler diameter. Further, no SPTs are collected and no undisturbed samples are collected.

The other type of exploration performed on the Siltronic site was CPT soundings. The CPT test is a common geotechnical test that consists of inserting a probe into the ground and recording the tip-bearing pressure (Qt), the pore pressure (u), and the side friction (Qc). Some of the CPT soundings at the Siltronic site were also equipped with TarGost detection equipment for detecting hydrocarbon plumes in the ground. No samples were collected. However, near-continuous readings are collected and correlations have been developed that identify soil type, strength, compressibility, modulus, permeability, and also correlate to some soil behavior issues such as liquefaction. One disadvantage of the CPT test is that the probe is expensive, and most operators will not push it through fill if the fill contains gravel or debris. Hence the majority of the CPT probes performed north of Fab 1 were predrilled, from 5 to 40 feet, through the fill zone, and no data were collected in the fill zone.

No geotechnical laboratory tests were found in the data reviewed.

Data Collection Strategy

Several alignments are under consideration for the interceptor trench on the Siltronic site, one north of the road, and one within the road, but south of the alluvial groundwater extraction wells. The geotechnical issues with either trench alignment are as follows:

- Short-term stability of the trench and existing slope between Siltronic site and river, and any impact it may have on Siltronic infrastructure or building
- Intermediate-term stability of the trench and the operation including trench consolidation, migration of fines into the trench causing settlement, and withdrawal of groundwater causing settlement upland of the trench
- Long-term stability of the trench/river bank caused by the trench in place and the details of the trench

Short-Term Stability

Chan and Yap (1992) did a study of the effects of digging a slurry trench adjacent to a historical building. The key issues they found that impacted the settlement adjacent to the trench, as well as stability of the trench, were (1) the ability to maintain a high slurry level, (2) the amount of time before backfilling (in their case, usually 24 hours or less), and (3) the length of trench open at any one time. The ground settlement impact of an open trench supported by slurry can extend back as far as 2*D (where D= the depth of the trench), but the primary impact is expected to be in the 1*D range (Peck, 1969). For a well-constructed and fluid-filled trench, the ground settlement impact is anticipated to be about 35 feet.

A key geotechnical data need for the short-term stability is to understand what the northern site boundary is composed of and where it lies in relation to the proposed trench. In CH2M HILL's experience, most of the fills on the Willamette River were constructed by building a berm on the river bank and filling behind it with river sand, debris, or upland soil, in several different sequences as was apparently done at Siltronic. The berms can be constructed of gravel, quarry rock, or rubble and can have permeability several orders of magnitude higher than the backfill soil. Excavating the trench through a rubble berm would likely result in a trench collapse, either by losing fluid rapidly through the trench, or by over-excavating rubble and oversized material which would increase the trench volume and the amount of time it is left open. Either case would cause additional ground movement adjacent to the trench, which could impact the river slope, the Siltronic buildings and facilities on the site. It is recommended that before any final trench alignment is chosen, the corridor be explored using cross-hole tomography to detect the presence or absence of rubble berms, and the location be adjusted accordingly. The preparation for performing a cross-hole tomography is to drill a soil boring, and to install a closed polyvinyl chloride (PVC) casing pipe into the borehole after the soil samples are taken.

Intermediate-Term Stability

After the trench is backfilled and operational, the intermediate-term issues are (1) the stability and volume control of the trench itself, (2) if the gravel backfill settles, (3) if fines migrate causing settlement, and (4) if the sheet pile is placed loosely enough that the ground settles around it and causes settlement adjacent to the sheet pile. These issues pertain primarily to the design and construction of the trench. However, the operation of the trench will involve depressing the water table, which could result in settlement of either fine-grained fill layers or fine-grained native material if the groundwater table is depressed to a greater depth, or for a longer period of time, than has been true in the past. The data required to evaluate this would come from consolidation tests performed on undisturbed soil samples, taken from geotechnical borings.

Long-Term Stability

The installation of the trench will impact the stability of the slope between Siltronic and the river. The material in the trench may be similar to the in situ fill material; however, the interface between the existing fill and the vinyl sheet pile and/or the gravel drain material and the vinyl sheet pile will likely be weaker than the existing fill or native material. This plane of weakness will impact the static slope stability of the existing slope above the river. The closer the trench is to the river, the more it will influence the strength. An operational issue that may also impact the slope stability is whether the groundwater is permitted to build up behind the vinyl sheet pile, creating an unbalanced driving force against the slope and possibly seepage force beneath the sheet pile. These conditions could be exacerbated by the remedy which is chosen for the sediment contamination in the Willamette River. If excavation is performed, reducing the resistance at the toe of the slope, the additional driving force would adversely impact the slope stability. Geotechnical information should be collected to evaluate the existing static slope stability and the possible change in slope stability due to the trench installation.

Recommended Geotechnical Data Acquisition

The key geotechnical issues regarding trench construction are short- and long-term stability. The intermediate-term issues of trench settlement, movement of fines, and pumping of groundwater are design and operation issues, which should be addressed in the design memorandum and the operations and maintenance plans.

If the trench is located as far north as possible, the edge of the slope is likely not feasible because it may run into rubble mounds, which make trench installation difficult and may also make it difficult for the trench to retain slurry. The farther north the trench is located, the greater impact the trench would have on the river bank slope stability. The farther south the trench is located, the greater impact the trench would have on the Siltronic structure, utilities, and road infrastructure.

A minimum of three geotechnical borings should be performed on the preferred alignment, with SPT samples taken at 2.5-foot intervals in the upper 40 feet. Where fine-grained soil is encountered, Shelby tube or Osterberg samples should be taken. Laboratory tests should be performed on fill material including moisture content, Atterberg limits, grain size, and percent passing the No. 200 sieve (P200). If fine-grained native soil is encountered, it should be sampled with Shelby tubes for laboratory strength and compressibility testing including consolidated-undrained triaxial testing (CUTX) with pore pressure measurements, and laboratory consolidation testing if groundwater drawdown is an issue. It is unlikely that the fill itself is uniform enough to sample and perform strength testing. The strength and consistency of the fill should be estimated through the SPT tests and the soil classification. The geotechnical borings should be a minimum of 100 feet deep.

A PVC casing should be grouted into the upper 50 feet of the boreholes to perform cross-hole tomography between the boreholes. If significant obstructions are discovered between the boreholes, the preferred alignment should be shifted south, out of the obstructions. Additional, shallower (to bottom of fill layer) borings with casings may be required to perform additional tomography and delineate a clear alignment.

Additional laboratory testing should be performed to delineate the interface friction between the vinyl sheet pile and the native fill material, as well as the granular drain material and the vinyl sheet pile. The strength and pore pressure response of the fine-grained layers should be adequate to also define those layers within the river area provided they can be correlated through existing CPT soundings that were taken in the river. The combination of geotechnical borings, geoprobe borings, rotosonic borings, and CPTs should give adequate stratigraphy to perform two-dimensional slope stability analysis on the slope between Siltronic and the river.

References

Chan, S.F. and Yap, T.F. 1992. “Effects of Construction of a Diaphragm Wall Very Close to a Masonry Building.” American Society of Testing and Materials STP 1129.

Gasco/Siltronic. 2013. *Fill WBZ Trench Investigation Work Plan-Shoreline Segments 1-2, NW Natural Property and the Northern Portion of the Siltronic Corporation Property Portland Oregon*. Prepared for Northwest Natural Gas. June.

Glynn Geotechnical Engineering. 2011. *Northwest Natural-Gasco Site Interceptor Trench Design Report.* April.

Peck, R.B. 1969. "Deep Excavations and Tunneling in Soft Ground." Proceedings of the 7th International Conference on Soil Mechanics and Foundation Engineering, State of the Art Volume.

ATTACHMENT 2

PASSIVE NAPL BARRIER DESIGN AND CONSTRUCTION

ARCADIS

Passive NAPL Barrier Design and Construction

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1. Introduction

In 2006, a “passive” non-aqueous phase liquid (NAPL) barrier was installed at New York State Electric & Gas Corporation’s (NYSEG’s) Court Street Former MGP Site in Binghamton, New York, USA (the Site). The term “passive” means that no pumping of groundwater is required for NAPL collection. The purpose of the NAPL barrier is to prevent on-site NAPL from migrating to the Susquehanna River, which is located less than 30 meters (m) downgradient of the site. The site had several complicating features including multiple active natural gas mains, a 170-centimeter diameter storm sewer, a major roadway, and a flood wall along the Susquehanna River.

The construction was the culmination of nine years of work involving site characterization, conceptual design development, site-specific multi-phase fluid-flow modeling, and remedial design. The design methods and techniques used to construct the NAPL barrier were innovative and selected specifically to address the complex site conditions. The NAPL barrier was constructed using a “design–build” approach where the engineer and the contractor were the same entity. The remainder of this document describes site conditions, data requirements for designing the NAPL barrier, NAPL barrier design, and construction methods.

1.1 Site History and Setting

Carburetted water gas was manufactured at the site from approximately 1888 to about 1939. At its peak, the plant produced about 300 million cubic feet of gas per year (Eng, 1984).

The site occupies a small parcel of land (approximately 1.75 hectares) in an industrial section of Binghamton, in Broome County, New York, USA and is identified as 271-291 and 293 Court Street (Figure 1). Several active gas mains were present at the site. The remaining portion of the site is now a gravel lot and used as an equipment storage and parking area for NYSEG.

To the south the site borders Court Street, a 4-lane highway that runs parallel to the Susquehanna River. East of the site is the 295 Court Street property, which contains a warehouse. Immediately north of the site is a major railroad line and yard, an asphalt works plant, and a scrap yard.

1.2 Site Geology and Hydrogeology

The general stratigraphy beneath the site consists of fill underlain by alluvial silt and clay, outwash sand and gravel, and dense basal till on top of shale bedrock (Figure 2). These units show a sequence of events specific to the site’s geologic history, which include:

1. Shale bedrock deposited as clay and silt in the Devonian Period
2. Relatively impermeable, dense basal till deposited by the Pleistocene glacier(s)
3. Outwash sand and gravel (referred-to hereafter as “sand and gravel”) deposited by meltwater rivers as the Pleistocene glacier(s) receded
4. Post-glacial alluvial silt and clay (referred-to hereafter as “silt and clay”), probably deposited in an abandoned river channel.
5. Fill and an assortment of man-made structures, originating from the site’s industrial history

As shown on Figure 2, the water table occurs at a depth of approximately 2 meters beneath the site. Along the alignment of the NAPL barrier, the saturated units of interest are the silt and clay and the sand and gravel. The hydraulic conductivities of these two units are estimated to be 1 meter per day (silt and clay) and 23 meters per day (sand and gravel). Groundwater moves generally southward, discharging into the Susquehanna River. Some groundwater in the silt and clay also moves downward into the sand and gravel.

The average flow of the Susquehanna River near the site is approximately 100 cubic meters per second (USGS, 2001).

1.3 Distribution of Subsurface NAPL

Dense NAPL (DNAPL) released at various locations has migrated downward, through the silt and clay and distributed itself complexly in the sand and gravel, reaching the top of till in at least one location. Pooled DNAPL has been identified on top of the till in one location and near the water table at a second location. Given the large quantities of petroleum feedstocks historically used at the site, the potential exists for pooled light NAPL (LNAPL) to be present, though none has been identified. MGP-related NAPLs were also present in shallow sediments in the river; however, it could not be determined whether these impacts were the result of subsurface NAPL migration, direct discharge through sewer pipes, or a combination of these two mechanisms. Figure 2 presents a conceptual model for groundwater/NAPL interactions at the Site.

2. Passive NAPL Barrier Conceptual Design

The objective of the passive NAPL barrier was to prevent on-site NAPL from migrating to the Susquehanna River. The conceptual design of the DNAPL portion of the NAPL barrier was based on two forces that govern movement of coal-tar DNAPL:

1. Gravity (downward or upward movement due to DNAPL density or LNAPL buoyancy, respectively)
2. Hydraulic gradient (primarily horizontal, in the sand and gravel, and toward the river).

The NAPL barrier conceptual design consisted of a graved-filled trench (installed along the downgradient site boundary) keyed into the underlying till. The hydraulic conductivity of the trench gravel would be considerably higher than that of the native sand and gravel, allowing groundwater to flow freely through the trench. NAPLs entering the trench will either settle to the bottom (DNAPL) or rise to the water table (LNAPL) due to their density contrast with the groundwater, and the decrease in hydraulic gradient in the trench caused by the permeable gravel backfill. The concept of the passive NAPL barrier has been described by White, et al. (2006a, b)

To evaluate the potential efficacy of the barrier trench concept, groundwater elevation data were collected for use in a groundwater flow model, the output from which was used as input for a multi-phase flow model, as described in the following subsections.

2.1 Conceptual Design Data Collection

As part of the conceptual design, a year-long fluid-level monitoring program was implemented to gather sufficient water-level data to evaluate the groundwater flow field near the flood wall and the river, near the presumed barrier alignment, and to monitor for accumulated NAPL. Evaluating the flow field was important because the direction and magnitude of hydraulic gradients are important factors governing the movement of MGP NAPLs. To accomplish this, fluid levels were measured and recorded using a combination of pressure transducers/data loggers (referred to hereafter as “data loggers”) and manual measurements over a period of approximately one year. Water-levels were measured and recorded automatically by data loggers at one-hour intervals at eight locations, including the river, beginning in February 2004. Manual water-level measurement rounds were conducted at a larger subset of monitoring locations bimonthly through May 2004 and then monthly thereafter. Additionally, at locations where NAPL was identified in samples recovered during drilling, an interface probe was used to check for accumulated LNAPL and/or DNAPL.

Collected data were analyzed using hydrographs and comparison of calculated vertical gradients at various points behind the flood wall and beneath the river. The collected data indicated that the groundwater-level fluctuations largely mirror changes in river level, indicating good hydraulic communication between the monitored wells and the river.

2.2 Conceptual Design Modeling

To evaluate the potential efficacy of the barrier-trench concept, a numerical, 3-D groundwater flow model was constructed using MODFLOW (McDonald and Harbaugh, 1988). The calibrated model layers and groundwater head distribution were imported into a multi-phase flow model (DNAPL 3D). The multi-phase flow model is a peer-reviewed finite-difference model presented by Gerhard et al. (1998; 2001; 2003a, b, c), and represents a three-dimensional extension of the original two-phase flow model presented by Kueper and

Gerhard (1995), and Kueper and Frind (1991a, 1991b). Results of the DNAPL3D modeling performed at this site were described by Kueper, et al. (2006).

3. Passive NAPL Barrier Design

A design-build approach was selected for the NAPL barrier construction. Under the design-build process, the design and work plan are prepared by the engineer in collaboration with the construction contractor. The design is a performance-based specification (rather than detailed specifications). The turn-key aspect of this approach is that the engineer (ARCADIS) and contractor (ARCADIS BBLES) are from the same company, providing services under a single contract to the client. This approach allowed for a streamlined design and fast-tracked construction after the treatability testing was completed. In addition, this approach allowed for quick response to unforeseen field conditions, without costly delays associated with change order negotiations. The specialized treatability testing and construction technologies were provided to ARCADIS BBLES under a subcontract by Geo-Solutions Inc. of Pittsburgh, PA (Geo-Solutions).

The primary components of the passive NAPL barrier consisted of:

1. A 75-centimeter (cm) wide permeable trench, filled with pea gravel and keyed into the underlying till (located approximately 12 – 18 meters below ground surface [bgs]). To construct this trench, a biopolymer slurry was selected (as further described below).
2. Low-permeability sections, installed using jet grouting techniques in areas where the gravel trench could not be installed (in areas beneath permanent utilities, retaining walls and drainage structures).
3. A DNAPL collection system consisting of horizontal collection pipes installed in the bottom of the trench and sloped to collection sumps with vertical recovery wells at low points within the till laver. The concept of the DNAPL collection system is to convey DNAPL through the pea gravel and lateral collection piping (along the top of till) into the DNAPL collection wells.
4. An LNAPL collection system that included a low permeability HDPE geomembrane barrier installed at the downgradient side of the trench to allow LNAPL to collect and be recovered via vertical collection wells.

The general alignment of the trench, along with the width and physical characteristics of the gravel were based on model inputs used in the multi-phase model described in Section 2.

3.1 Pre-Design Investigation

A pre-design investigation (PDI) was conducted to obtain additional information required to complete the design of the NAPL barrier. The PDI activities included installing geotechnical borings along the proposed NAPL barrier alignment at approximate 100-foot intervals. The proposed borings were necessary to confirm the various soil types that would be encountered during trench installation, locate the till layer along the proposed alignment, assess the potential for obstructions to trench installation (such as large boulders), and assess the geotechnical properties of the soil materials that would be encountered during trench installation. This information was also used to determine the characteristics of the slurry to be used to install the trench. Following completion of the PDI, treatability testing of the materials to be used to support construction was conducted and the final construction documents were prepared

3.2 Jet Grout Testing and Mix Design

Jet grouting was selected to construct portions of the NAPL barrier in areas where obstructions could not be relocated or removed (such as natural gas mains and the 168-cm diameter storm sewer). Jet-grouting consists of injecting ultra high-pressure fluids or binders into the soil at high velocities (approximately 300 m/sec). Jet-grouting completely breaks down the soil structure and mixes soil particles in-situ with a binder to create a homogeneous mass, which in time solidifies and forms a low permeability barrier.

ARCADIS' geotechnical subcontractor, Geo-Solutions, Inc. (Geo-Solutions), conducted a bench-scale jet grout testing program to determine appropriate jet grout mix designs that would meet a permeability goal of less than 1×10^{-6} centimeters per second (cm/sec) and demonstrate long-term compatibility with site constituents. Based on the results of the testing program, a jet grout mix consisting of Portland cement, BFS, and bentonite was selected. The treatability test results demonstrated that this mix would meet the required permeability of 1×10^{-6} cm/sec, and was compatible with the site-related NAPL.

3.3 Biopolymer Slurry Testing and Mix Design

Slurry wall technology using biopolymer (BP) slurry was selected as the method to support the trench excavation during construction of the passive NAPL barrier. BP slurry is a mixture of water and natural (or synthetic) polymers and stabilizers that are used in place of traditional trench shoring and dewatering methods.

Geo-Solutions conducted bench-scale laboratory testing to evaluate the stability (i.e., viscosity, density, and pH) of various biopolymer slurry mixes when combined with the site groundwater, site soils, and NAPL collected from the site. Additionally, a polymer degradation agent (i.e., an “enzyme breaker”) was evaluated for compatibility with the site-specific biopolymer mix designs. The enzyme breaker is used to degrade the BP slurry following installation of the NAPL barrier components.

The bench-scale test procedures were designed to simulate potential field conditions at different stages of the NAPL barrier interim remedial measure (IRM) construction including: excavation; backfill placement; and slurry degradation (i.e. adding the enzyme breaker). A guar gum-based (carbohydrate derived from the guar bean) slurry and a polyacrymide-based slurry were tested for the stability criteria described above. The guar gum test slurry was slightly more viscous and the polyacrymide slurry was slightly less viscose than ideal; however, both slurries demonstrated stable viscosities prior to the addition of the slurry breaker. The slurries remained active (e.g., viscosity of 60 seconds or greater using the Marsh Funnel technique) during the test period and did not indicate potential incompatibility with site soil, groundwater, NAPL, or with the enzyme breakers. Following the addition of the enzyme breaker, the viscosities of both slurries decreased to that of water, demonstrating that the breaker and the slurries were compatible.

Based on the results of the bench-scale testing, a mixture of guar gum and stabilizers was selected as the biopolymer slurry. A breaker material consisting of hydrogen peroxide was chosen to degrade the slurry following installation of the gravel trench and collection system.

4. Passive NAPL Barrier Construction

4.1 Mobilization and Site Preparation

ARCADIS BBLES and its remedial subcontractor (Geo-Solutions) installed the NAPL barrier between July 10, 2006 and November 22, 2006. Mobilization and site preparation activities included:

1. Documenting existing site conditions including identifying aboveground and underground utilities, equipment, and structures, as necessary to implement the IRM activities.
2. Removing abandoned natural gas lines that interfered with the NAPL barrier alignment.
3. Relocating utilities to facilitate NAPL barrier construction.

4.2 Pre-Trench Excavation

A critical component of the NAPL barrier construction was the pre-trench excavation. The pre-trench excavation was performed to locate or remove underground utilities or obstructions along the alignment of the NAPL barrier. During the performance of pretrenching, the following obstructions were observed:

1. Two underground steel structures
2. Over 20 (primarily abandoned) underground pipelines. The pipelines were exposed, removed from the trench alignment, and plugged with expandable polyurethane spray foam.
3. A large amount of construction material debris and four buried concrete foundation walls were encountered in the western portion of the site. The foundation walls were up to 1.2 m-thick and the wall bottoms were located approximately 5.2 m bgs. The fill material around these concrete foundation walls comprised primarily of masonry materials (bricks and large sections of reinforced concrete) and structural steel. There was very little soil and the fill materials had little to no cohesiveness; therefore, imported cohesive soil (saw clay) was used to backfill these pretrenched areas to facilitate excavation of the gravel-filled trench.

To install the gravel-filled trench in the area of buried debris and foundation walls, the foundation walls had to be removed from the trench alignment. Due to the integrity of the concrete foundation walls and the lack of cohesion in the surrounding fill materials, removal of the four concrete foundation walls and installation of the gravel-filled trench as originally proposed was not feasible. As a result, the design of the NAPL barrier was modified as follows:

1. A sonic drill was used to predrill areas of the barrier alignment (that were filled with debris) between 3 of the 4 foundation walls to approximately 6 m bgs, to facilitate jet grouting. In addition, a sonic drill was used to drill up to 20 boreholes through one of the existing concrete foundation walls to facilitate removal.
2. Approximately 6 m of the NAPL barrier was jet grouted to form a low permeable barrier between three of the foundation walls, and extending into the till layer. The pilot holes created using the sonic drill were used to facilitate jet grouting through the debris.
3. One of the existing concrete foundation walls was removed, following the sonic drilling without further damage to the trench sidewalls.

4.3 Jet Grout Wall Installation

The jet grout walls were installed along the NAPL barrier alignment in areas where trench excavation was not feasible due to underground obstructions (Figure 3). Jet grouting was conducted before the gravel portion of the barrier was constructed, to allow the grout adequate time to cure. The grout walls were installed using a track-mounted rotary drill rig, a grout batch plant, and jet-grout pump. Once the holes were drilled to the appropriate depth (at least 15 cm into the top of the underlying till layer), the jet-grouted columns were formed by rotating and lifting the drill string while a high pressure stream of grout was forced out of the side nozzles using pressures of at least 210 kilograms per square cm (Ksc). The jet-grouted sections were formed by installing two rows of overlapping jet grout columns.

During the performance of the jet grout wall installation activities, grout spoil material (i.e., excess grout) was collected within a trench along the alignment of the NAPL barrier. The grout spoil material was allowed to solidify within the trench and was then removed from the trench at the beginning of each day, and was stockpiled in the waste material staging area for subsequent offsite transportation and disposal.

During the jet grout wall installation, quality control testing was performed on the jet grout mixture and included the following:

1. Fresh grout slurry was tested onsite for unit weight and viscosity Marsh Funnel twice per shift in accordance with ASTM D-4380 and API RP 13B-1, respectively.
2. Insitu soilcrete (created during the jet grouting application) samples were collected using an insitu sampler (cylinder), before the soilcrete began to cure, at frequency of one sample per 300 vertical meters of (installed) jet grout column. The soilcrete samples were collected, handled, packaged, and tested for unconfined compressive strength (UCS) (in accordance with ASTM D1633) and permeability (in accordance with ASTM D5084). The testing results indicated that the permeability of the jet grout wall ranged from 7×10^{-7} to 2.4×10^{-8} cm/sec, which were approximately two orders of magnitude lower than the design objective of 1×10^{-6} cm/sec. The UCS ranged from 20 Ksc to 60 Ksc. Although UCS was not a specified performance criteria, the associated results are consistent with UCS of controlled low-strength material (e.g., flowable fill). For comparison, cohesive soils, such as clay, typically have compressive strengths in the vicinity of 1.5 Ksc.

4.4 Gravel-Filled Trench

Upon completion of the jet grout wall installation activities, the gravel-filled trench sections of the NAPL barrier were constructed. The gravel-filled trench sections of the NAPL barrier were constructed to facilitate the collection and removal of mobile or potentially mobile NAPL along the trench alignment. The trench excavation was performed using biopolymer slurry to allow for the placement of DNAPL and LNAPL collection systems and pea gravel. Upon the placement of pea gravel within the trench, the biopolymer slurry was degraded to promote the free flow of groundwater through the trench. Additional details related to the construction of the gravel-filled trench are provided below.

4.4.1 Trench Excavation

The trench was excavated using an extended-reach excavator and was keyed a minimum of 150 cm into the top of the till unit located approximately 12 to 18 m bgs, and the average width of the trench was approximately 75 cm. The anticipated depth of the trench was based on pre-design information and the actual top of till elevation was measured and documented during the trench excavation activities. Once the top of till elevation was measured and documented, additional till material was excavated to attain a minimum key of 15 cm into the top of the till unit to confirm the proper placement of the DNAPL collection system.

During the trench excavation, the trench stability was maintained using biopolymer slurry, which was mixed onsite using a venturi mixing device and holding tanks. As the excavation progressed, the biopolymer slurry was pumped from the onsite holding tanks to the trench, and the level of the biopolymer slurry was maintained at least 1 m above the groundwater table elevation and no more than 0.6 m bgs. During the use of biopolymer slurry, quality control testing was performed on the biopolymer slurry and included the following:

- pH testing (minimum pH of 9) and viscosity testing (minimum viscosity of 60 seconds Marsh Funnel Viscosity) was performed on the plant-mixed (i.e., slurry that had not yet been placed in the trench) biopolymer slurry a minimum of two times daily.
- pH testing (minimum pH of 8) and viscosity testing (minimum viscosity of 50 seconds Marsh Funnel Viscosity) was performed on the active biopolymer slurry (i.e., slurry in the trench excavation prior to degradation) a minimum of two times daily.

Materials excavated from the trench were drained with the excavator bucket (to remove excess biopolymer slurry/groundwater to the extent feasible) and placed in a waste material staging area either directly from the excavator bucket or by using a dump truck to transport the material from the excavation to the staging area. The excavated materials in the waste material staging area were dewatered via gravity drainage, and the collected water was placed in an onsite storage tank for subsequent offsite transportation and disposal. In addition to gravity dewatering, some excavated materials required the addition of cement to properly solidify the material for offsite transportation and disposal.

During the trench excavation on the western portion of the site (in a 30 m section of the trench), ARCADIS BBLES and its subcontractor, Geo-Solutions, observed that the biopolymer slurry level dropped significantly (approximately 2.5 to 3 m bgs) within a short time period (approximately 10 to 20 minutes). The trench was visually reviewed to determine the reason for the slurry loss, but the cause could not be determined. After the significant drop in the biopolymer slurry level, cracks began to develop in the Court Street asphalt pavement approximately 7.5 m downgradient from the excavated trench. As a result of this condition, the trench was immediately backfilled with pea gravel to prevent further damage. This effort required working around the clock to backfill the trench as quickly as feasible to prevent additional damage, as well as closing a portion of Court Street to prevent vehicular traffic from travelling over the cracked area. Once the trench was backfilled with pea gravel, the area was stabilized and no further movement of the asphalt pavement was observed.

Additional efforts were made to determine the cause of the biopolymer slurry loss; however, these efforts were unsuccessful and the cause of this biopolymer slurry loss could not be determined. These efforts included re-excavating areas along the trench to locate potential voids or pipelines, as well as observing areas along the north bank of the Susquehanna River adjacent to the site. Based on these efforts, there were no observations of voids or pipelines within the trench, and there were no observations that the biopolymer slurry drained to the river.

As a result of quickly backfilling the trench with pea gravel, various components of the DNAPL and LNAPL collection systems were not installed. In order to complete the excavation activities in this area, a 3 m long grouted plug was installed (using driven pipe and pressure grouting) for the entire depth of the trench to create a vertical wall that would retain the area backfilled with pea gravel and allow the remaining area to be excavated (thus preventing the pea gravel from sloughing into the excavated area).

Additional efforts were initiated to re-excavate the trench under slurry in this portion of the site and install the LNAPL collection system components in this area; however, this effort was unsuccessful because the trench was unable to hold the biopolymer slurry and the trench walls were collapsing at an excavation depth of 3 m bgs. Based on this condition, installing the HDPE geomembrane, LNAPL collection well, and 15 cm diameter HDPE slotted lateral collection pipe within an open excavation was not feasible and there was a risk of creating further damage to the adjacent Court Street asphalt pavement. As a result, the 15 cm diameter HDPE slotted lateral collection pipe was not installed in this area and flat steel sheeting with an Adeka sealant for the interlocking joints was installed in this area in lieu of the HDPE geomembrane. In addition, a new DNAPL and LNAPL collection well were installed using a drill rig at the east side of the grout plug as this was a low point for the underlying till unit.

4.4.2 DNAPL Collection System Installation

The DNAPL collection system consisted of lateral collection piping and vertical collection wells. The lateral collection piping consisted of 15 cm diameter, 90-slot (2 millimeter [mm] slot size) HDPE piping, and was placed along the top of the till surface (that was keyed a minimum of 15 cm into the surrounding till). The vertical collection wells consisted of 20-cm diameter, 304 stainless steel well screen (90-slot) and solid riser pipe.

For the majority of the NAPL Barrier, the DNAPL collection system was constructed once the trench was excavated (under biopolymer slurry) a minimum of 15 cm into the top of till layer to create a positive slope. In the area of the trench collapse, as described above, the horizontal piping was not installed. At the DNAPL collection well locations, the trench was excavated at least one foot deeper below the lateral collection piping elevation to form a sump. A critical factor during the trench excavation activities was to maintain a positive slope along the top of till into the DNAPL collection well sumps. The lateral collection piping was assembled (butt fusion welded) on the ground surface and was lowered into the trench using concrete weights as ballasts to counteract the buoyancy forces of the piping. The DNAPL collection wells were assembled (thread connections) on the ground surface and were lowered into the trench within the excavated sump (Figure 4). The DNAPL collection wells contained a 3 m long well screen with end cap at the bottom of the well.

4.4.3 LNAPL Collection System Installation

The LNAPL collection system consists of 60-mil HDPE geomembrane and vertical collection wells. The LNAPL collection wells consist of 20 cm diameter, 304 stainless steel well screen (90-slot) and solid riser pipe, and were installed adjacent to each of the DNAPL collection wells. The concept of the LNAPL collection system is that the HDPE geomembrane as a barrier will prevent offsite migration of mobile NAPL, and the LNAPL collection wells will be used to facilitate monitoring and recovery of LNAPL.

The LNAPL collection system was constructed after the trench was excavated (under biopolymer slurry) and a portion of the trench was backfilled with pea gravel. The LNAPL collection wells were assembled (thread connections) on the ground surface and were lowered into the trench and positioned on top of the pea gravel at the appropriate elevation (approximate elevation 872 AMSL). The LNAPL collection wells contained a 3-m long well screen at the bottom of the well, and the remainder of the well consisted of a solid riser section.

Both the bottom of the HDPE geomembrane and LNAPL recovery wells extended approximately 0.6 m below the annual low groundwater table elevation The HDPE geomembrane was installed vertically on the downgradient side of the trench. The HDPE geomembrane was temporarily staked at the ground surface on the downgradient side of the trench and was lowered into the biopolymer slurry using weights attached to the bottom of the geomembrane to prevent the geomembrane from floating in the biopolymer slurry (Figure 5). The HDPE geomembrane panels were overlapped a minimum of 1.2 m to create a continuous LNAPL barrier on the downgradient side of the NAPL Barrier. After the HDPE geomembrane was installed, backfilling resumed within the trench using pea gravel up to approximately 1 m bgs. At this point, the temporary stakes were removed and the HDPE geomembrane was placed over the width of the trench (covering the pea gravel) for the subsequent placement of the remaining backfill and surface restoration.

4.4.4 Backfill Placement

After the installation of the DNAPL collection system, the excavated trench was backfilled with pea gravel up to approximate 2.1 m bgs. After the pea gravel was placed to approximately 2.1 m bgs (with a median diameter of approximately 12 mm), the LNAPL collection system was installed, followed by the placement of additional pea gravel up to approximately 1 m bgs. At this point, the HDPE geomembrane was placed over the top of the pea gravel, and additional backfill was placed up to approximately 30 cm bgs in areas receiving asphalt or stone surface restoration and approximately 15 cm bgs in areas receiving topsoil and grass seed (additional information related to surface restoration is included in Section 2.8).

Approximately 4,100 tonnes of pea gravel (with a median diameter of 12 mm) were used to backfill the trench for the NAPL barrier construction.

4.4.5 Biopolymer Slurry Degradation

During and following the placement of pea gravel within the trench, the biopolymer slurry was degraded to promote the free flow of groundwater through the trench. The degradation process consisted of installing a series of temporary well points at various locations within the trench and pumping the biopolymer slurry and the enzyme breaker (hydrogen peroxide) from the temporary well points on the surface of the trench. This process of recirculating the biopolymer slurry and the enzyme breaker was continued until a maximum Marsh

Funnel viscosity of 30 seconds was attained and the pH of the biopolymer was approximate 7 S.U. Upon completion of the biopolymer slurry degradation process, the temporary well points were removed from the trench.

4.4.6 Site Restoration

Upon the completion of backfilling the gravel-filled trench, the site surface was restored, and various underground/overhead utility lines were reactivated.

5. Post-Construction Monitoring

An initial (12-month) monitoring plan for the NAPL barrier trench was developed to determine optimal monitoring and NAPL recovery methods and frequencies. Post-construction monitoring has been conducted monthly to assess the location and amount of NAPL that enters the trench and to monitor the area between the trench and the Susquehanna River for the presence of NAPL. To date, recoverable amounts of NAPL have not accumulated within the trench, only odors, sheens and trace amounts of NAPLs.

FIGURES:

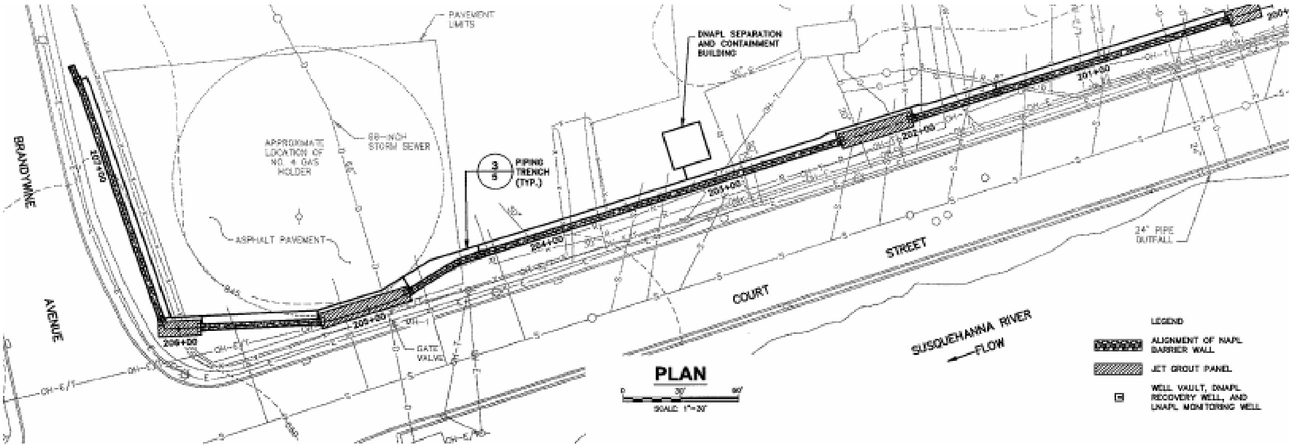

Figure 1 – Site Layout and NAPL Barrier Alignment (North is towards the top of the page)

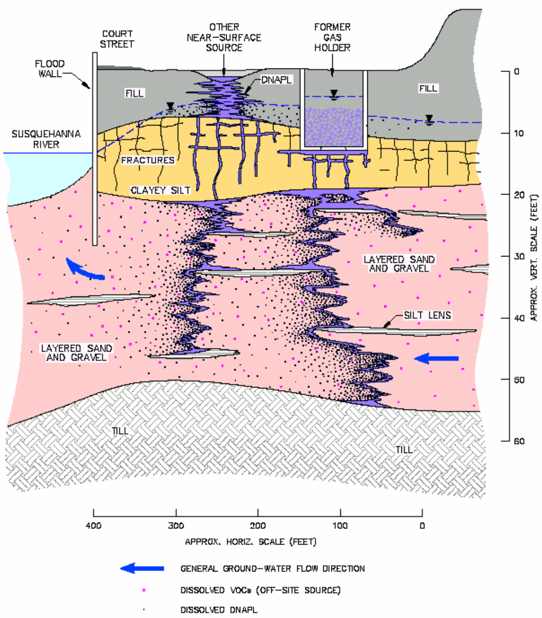

Figure 2 – Conceptual Site Model

Figure 3 – Jet Grouting

Figure 4 – Installation of DNAPL Collection Well

Figure 5 – Placement of HDPE Barrier

References

1. United States Geological Survey (USGS), 2007. *USGS Surface-Water Annual Statistics for the Susquehanna River at Conklin, New York (Station #01503000).* www.waterdata.usgs.gov.
2. Eng, Robert. 1984. SURVEY OF TOWN GAS AND BY-PRODUCT PRODUCTION AND LOCATIONS IN THE U.S. (1880-1950), EPA/600/S 7-85/004
3. White, K.A., B.H. Kueper, M.J. Gefell, and T.L. Blazicek 2006. “Passive NAPL Barriers - Concepts and Case Histories.” In Proceedings of Natural Gas Technologies 2006 -Energy and the Environment, ed. Gas Technology Institute. 22-25 October, Orlando, FL.
4. White, K.A., M.O. Gravelding, M.J. Gefell, D.G. Bessingpas, and M. Slenska. 2006. "Design, Installation, and Operation of a Passive NAPL Barrier at a Former Wood-Treating Site." In Proceedings of the Fifth International Conference on Remediation of Chlorinated and Recalcitrant Compounds, 24-27 May, Monterey, CA. ISBN 1-57477-157-4.
5. McDonald, M.G. and A.W. Harbaugh, 1988. A modular, Three-Dimensional, Finite-Difference Groundwater Flow Model, USGS Techniques of Water Resource Investigations (Book 6).
6. Gerhard, J.I. and Kueper, B.H., 2003a. Capillary pressure characteristics necessary for simulating DNAPL infiltration, redistribution, and immobilization in saturated porous media. Water Resources Research, 39 (8), pp. SBH 7-1 – 7-17.
7. Gerhard, J.I. and Kueper, B.H., 2003b. Influence of constitutive model parameters on the predicted migration of DNAPL in heterogeneous porous media. Water Resources Research, 39(10), pp. SBH 4-1 – 4-13.
8. Gerhard, J.I. and Kueper, B.H., 2003c. Relative permeability characteristics necessary for simulating DNAPL infiltration, redistribution, and immobilization in saturated porous media. Water Resources Research, 39 (8), pp. SBH 8-1 – SBH 8-16.
9. Kueper, B.H. and Gerhard, J.I., 1995. Variability of point source infiltration rates for two-phase flow in heterogeneous porous media. Water Resources Research; Vol. 31, No. 12, pp. 2971-2980.
10. Kueper, B.H. and Frind, E.O., 1991a. Two-phase flow in heterogeneous porous media, 1. Model Development. Water Resources Research, Vol. 27, No. 6, pp. 1049-1057.
11. Kueper, B.H. and Frind, E.O., 1991b. Two-phase flow in heterogeneous porous media, 2. Model Application. Water Resources Research, Vol. 27, No. 6, pp. 1058-1070.
12. B.H. Kueper, K.A.White, K.A., M.J. Gefell, and T.L. Blazicek, 2006. "Design of a Passive NAPL Collection Barrier". In Proceedings of the Fifth International Conference on Remediation of Chlorinated and Recalcitrant Compounds, 24-27 May, Monterey, CA. ISBN 1-57477-157-4.
13. BBL 2005. Letter to Mr. Anthony Karwiel, New York State Department of Environmental Conservation regarding NYSEG Binghamton Court Street MGP Site, Conceptual NAPL Barrier Design (November 3, 2005).
14. BBL, 2006. NAPL Barrier *Interim Remedial Measure Work Plan, Binghamton Court Street Former Manufactured Gas Plant Site*, Binghamton, New York (July 2006).
15. ARCADIS BBL, 2007. NAPL Barrier *Interim Remedial Measure Engineering Certification Report*. (March 2007).